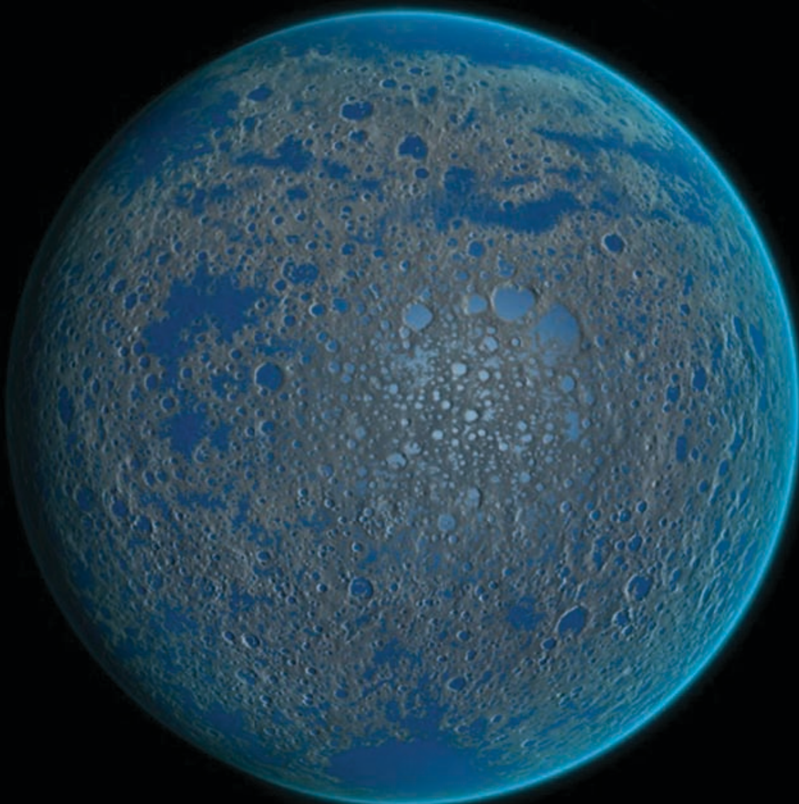
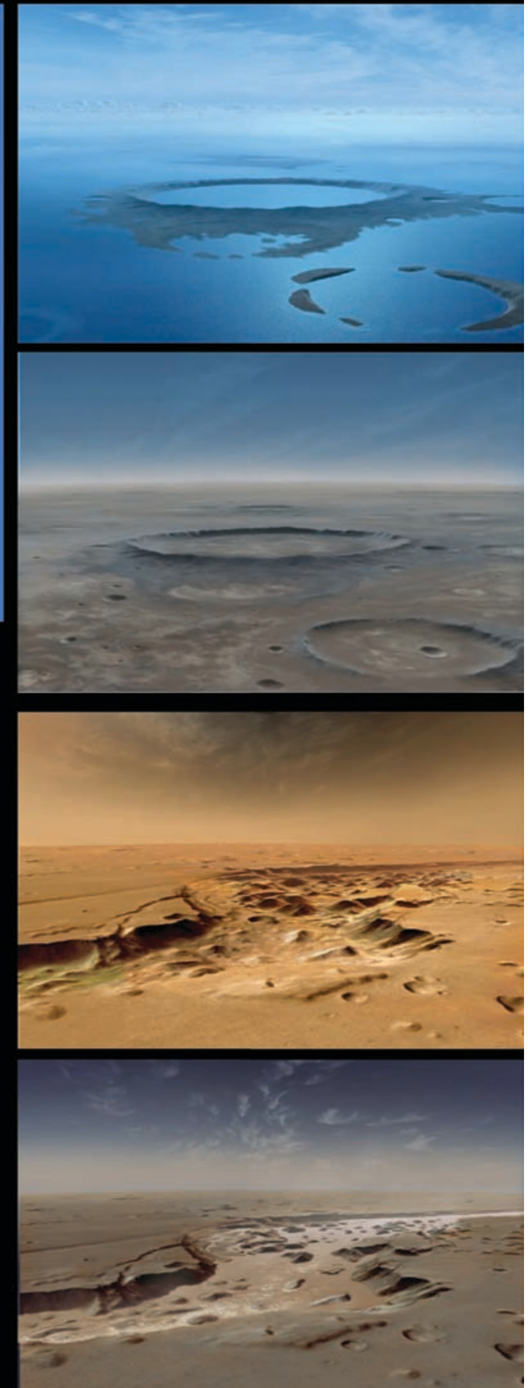
Mawrth Vallis

preserving the origins

Geology and planetary context of the MSL Landing Site at Mawrth Vallis





E. Noe Dobrea, J. Mustard , J-P. Bibring, J. Bishop, J. Carter, B. Ehlmann, D. Loizeau, N. Mangold, N. McKeown, J. Michalski, M. Parente, F. Poulet, J. Wray

Key Highlights of Mawrth Vallis

1. Section of Noachian Crust with in-place deposits
2. The stratified mineral sections (Al, Mg, Fe phyllosilicates) show they formed in-situ
3. Evidence for diverse fluvial processes
4. The mafic cap is Hesperian in age and unaltered

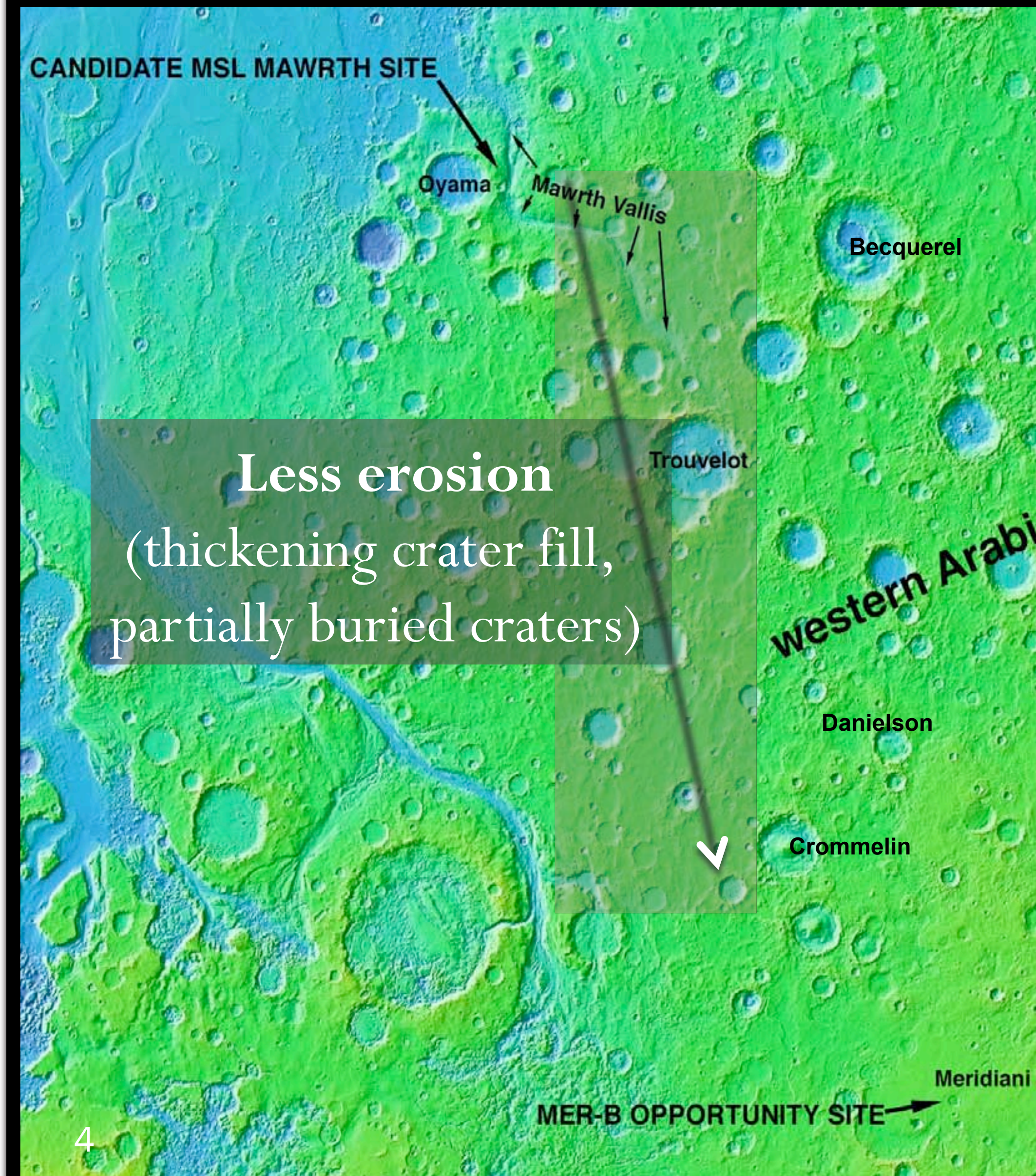
Also: At Mawrth MSL Will Traverse the Noachian to Hesperian.

1. MSL Instruments to measure the contrasting mineral sections will sample different environments
2. Isotopic measurements across the Noachian-Hesperian

Outline

1. Geological context
2. Dominant morphologies
    1. Layering and structure
    2. Valleys/Channels
    3. Geological units of the landing ellipse
3. Oyama's ejecta and resurfacing
4. Formation Scenarios and current models
5. Remaining unknowns and MSL

Geological context



- Evidence for buried and exhumed craters, channels, layers is seen throughout Arabia
- Arabia Terra is highly eroded
- Northern region appears more eroded than southern (on the basis of crater fill)
- Most of Arabia bedrock is now covered by regolith (including dust)
- *Bedrock around Mawrth Vallis is fully exposed*

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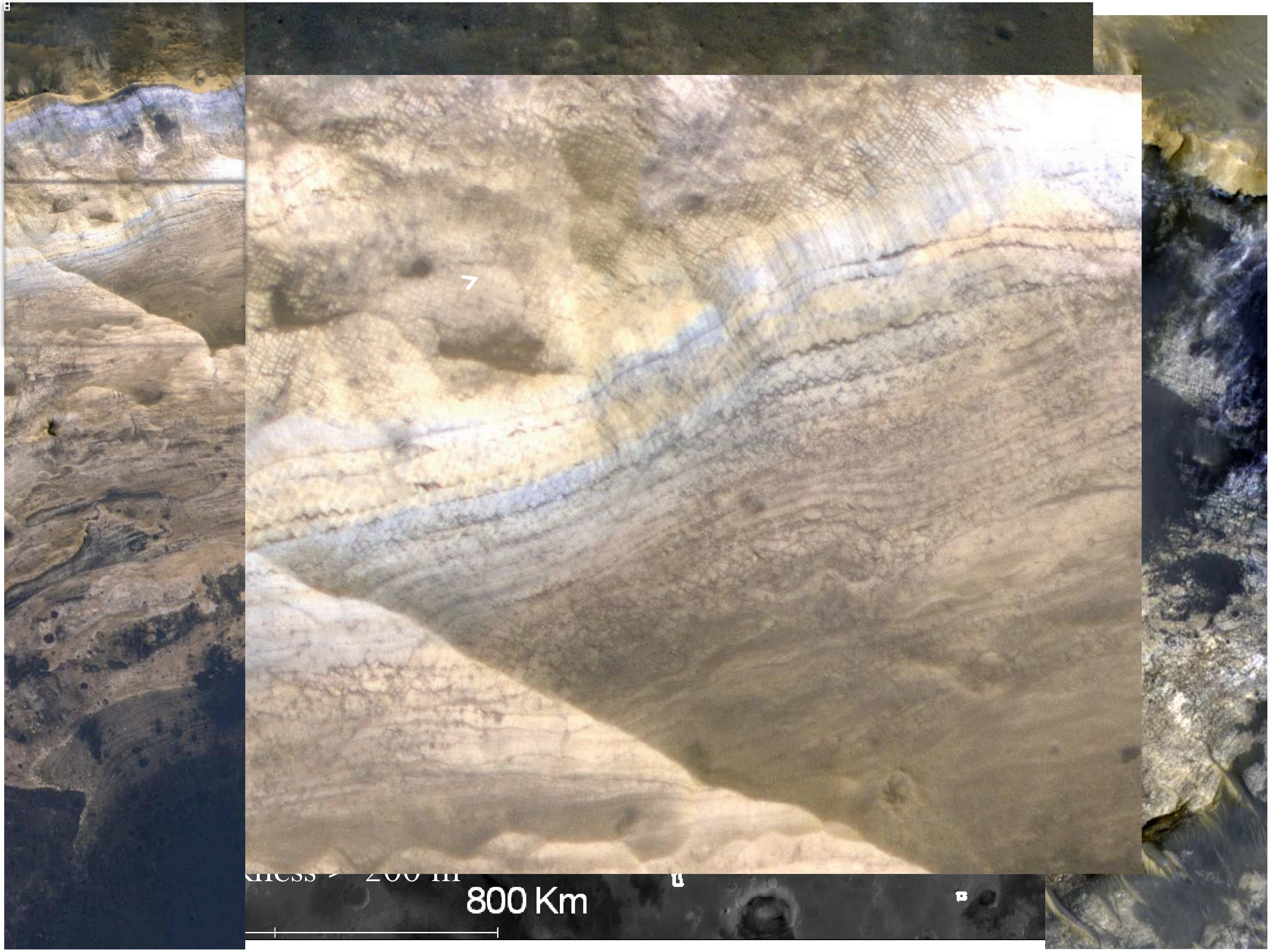
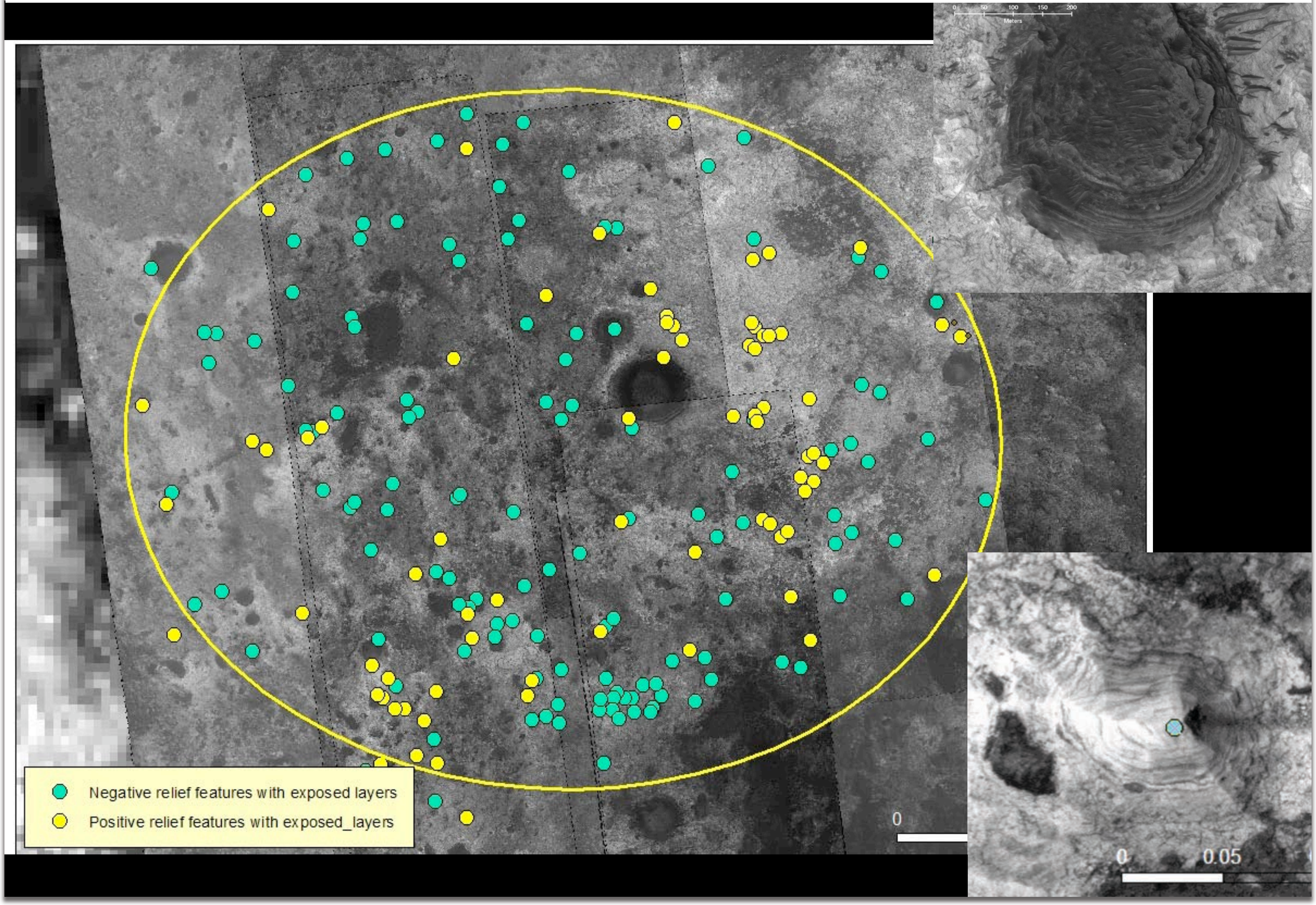

800 Km

Layers within ellipse (observed with HiRISE)

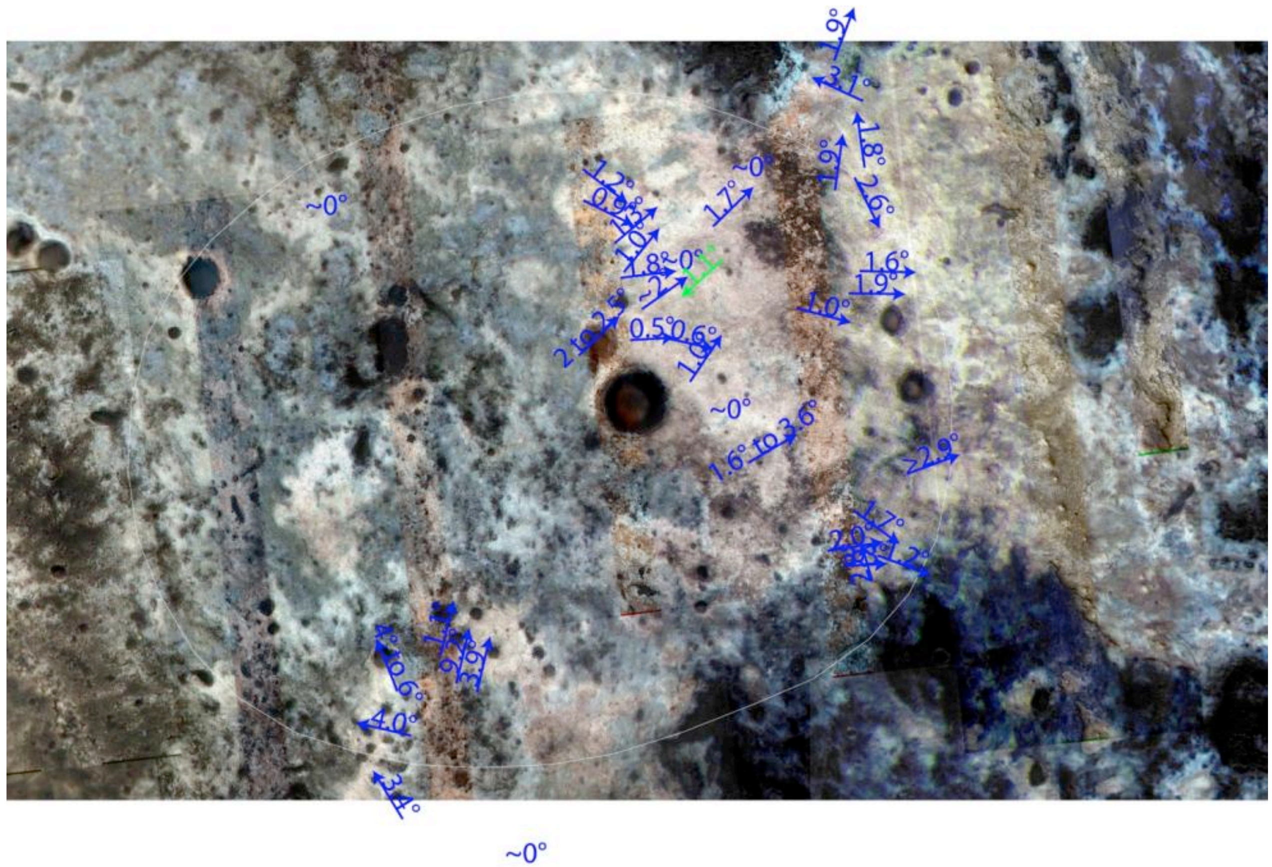


Structure

Loizeau:

- Where dips can be measured, apparent dips are <3 degrees
- Regional trends with local variations

Compositional boundary appears to follow modern topography (Wray et al, 2008)



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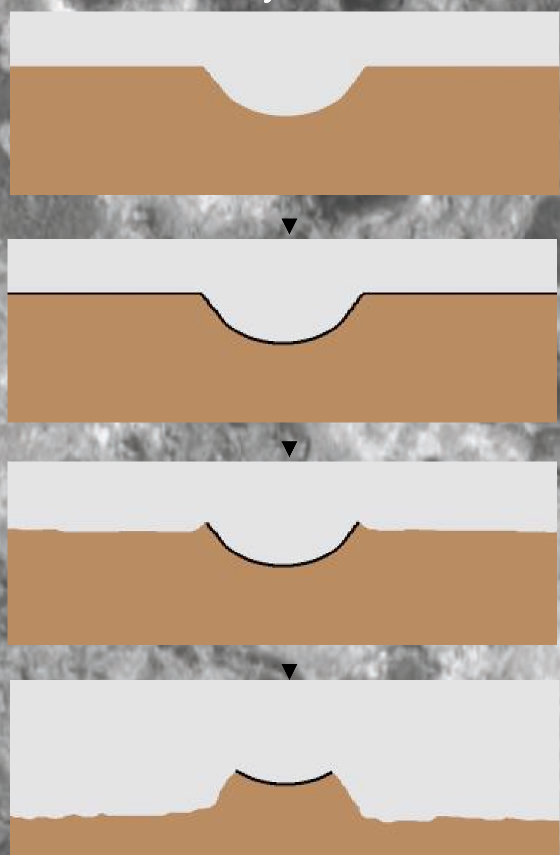
CTX Image P12_005898_1999

5 km

Topographic inversion: Craters and channels

Protection by resistant unit

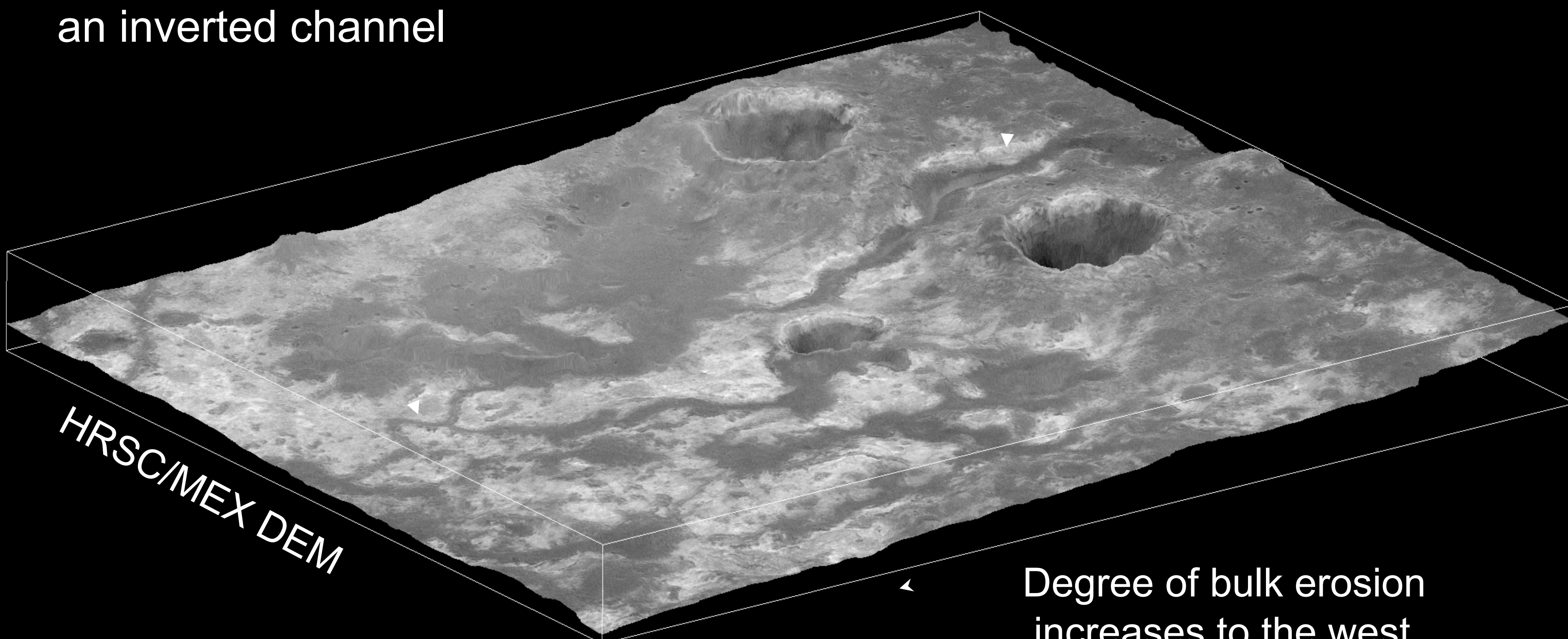


- Craters, fluvial channels, and veins/dikes occur in positive relief throughout the region
- These features commonly have topographic relief several 10s of meters above the surroundings, suggesting 10s (but not 100’s) of meters of erosion.

Inverted channels are observed at the following of « true » valleys dissecting the phyllosilicates-bearing bedrock

100 m deep valley

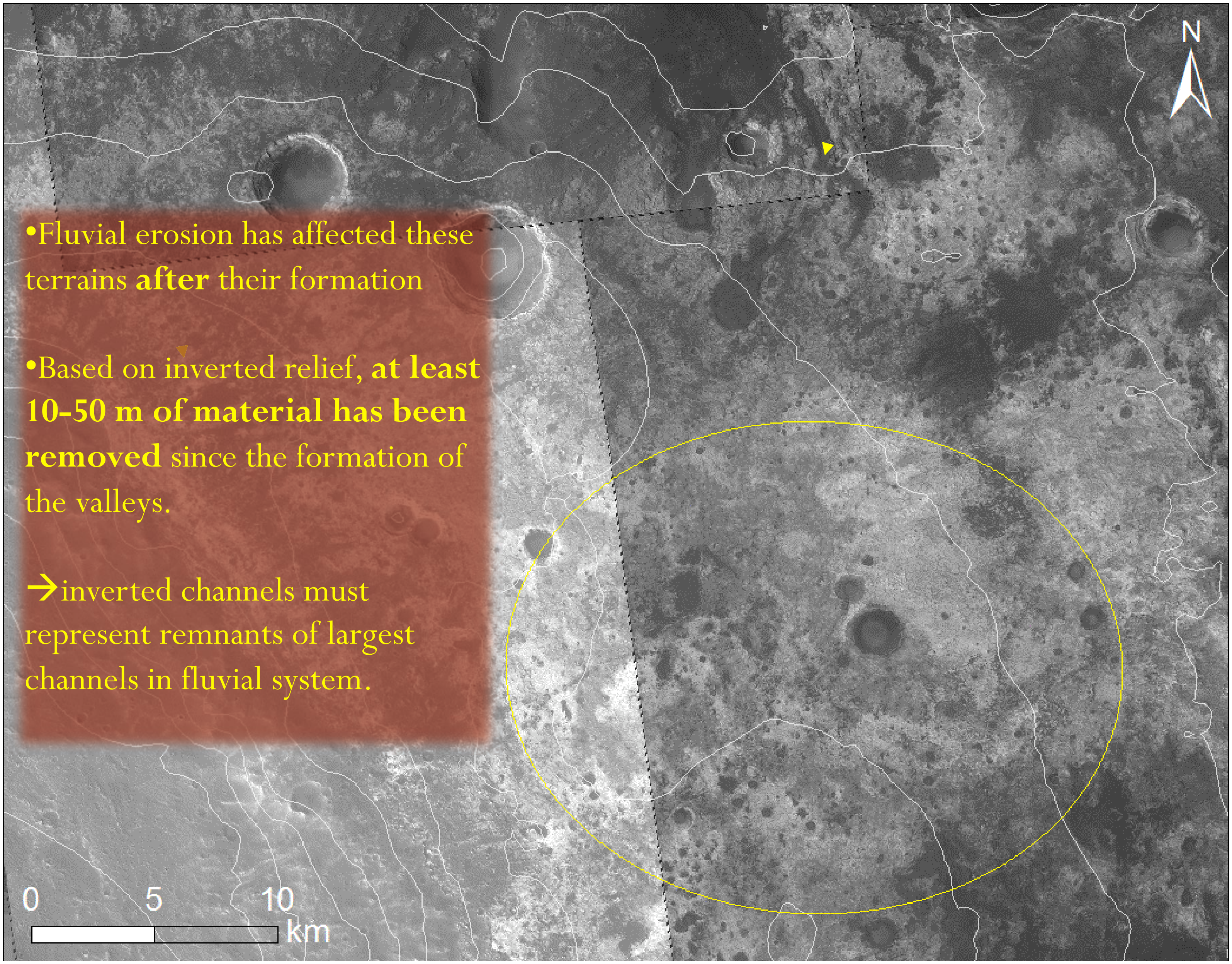
Shallow relief of an inverted channel



Degree of bulk erosion increases to the west

Small parallel inverted valleys(?) on walls of Oyama follow topography

Large valleys also correlate well with topography north of ellipse



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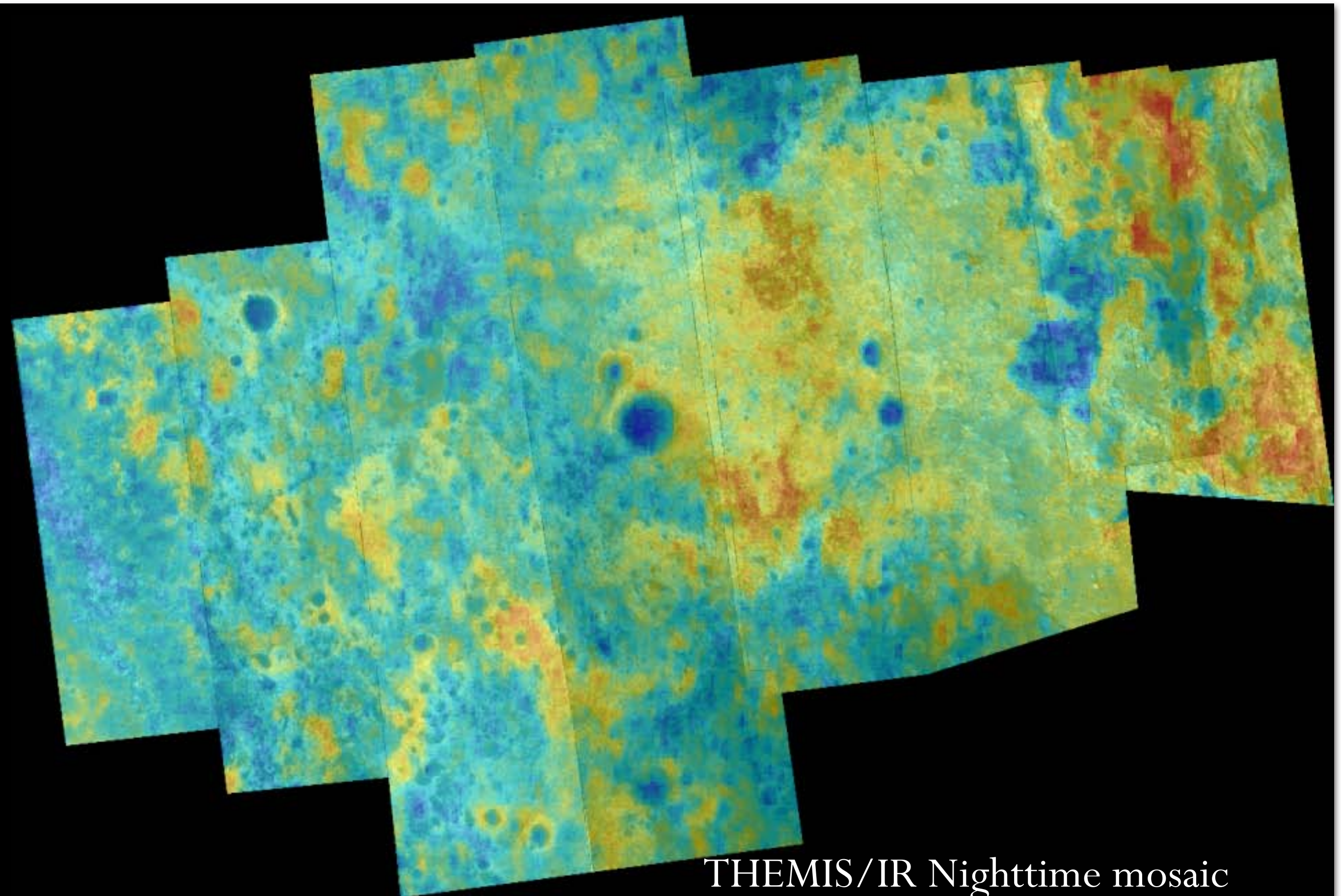
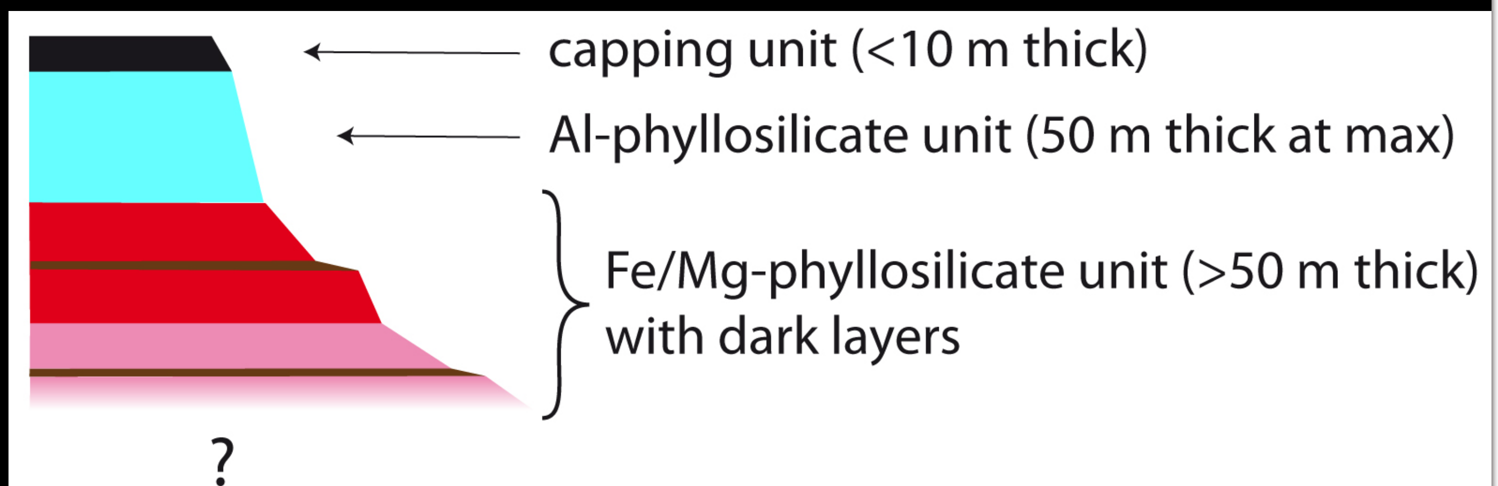
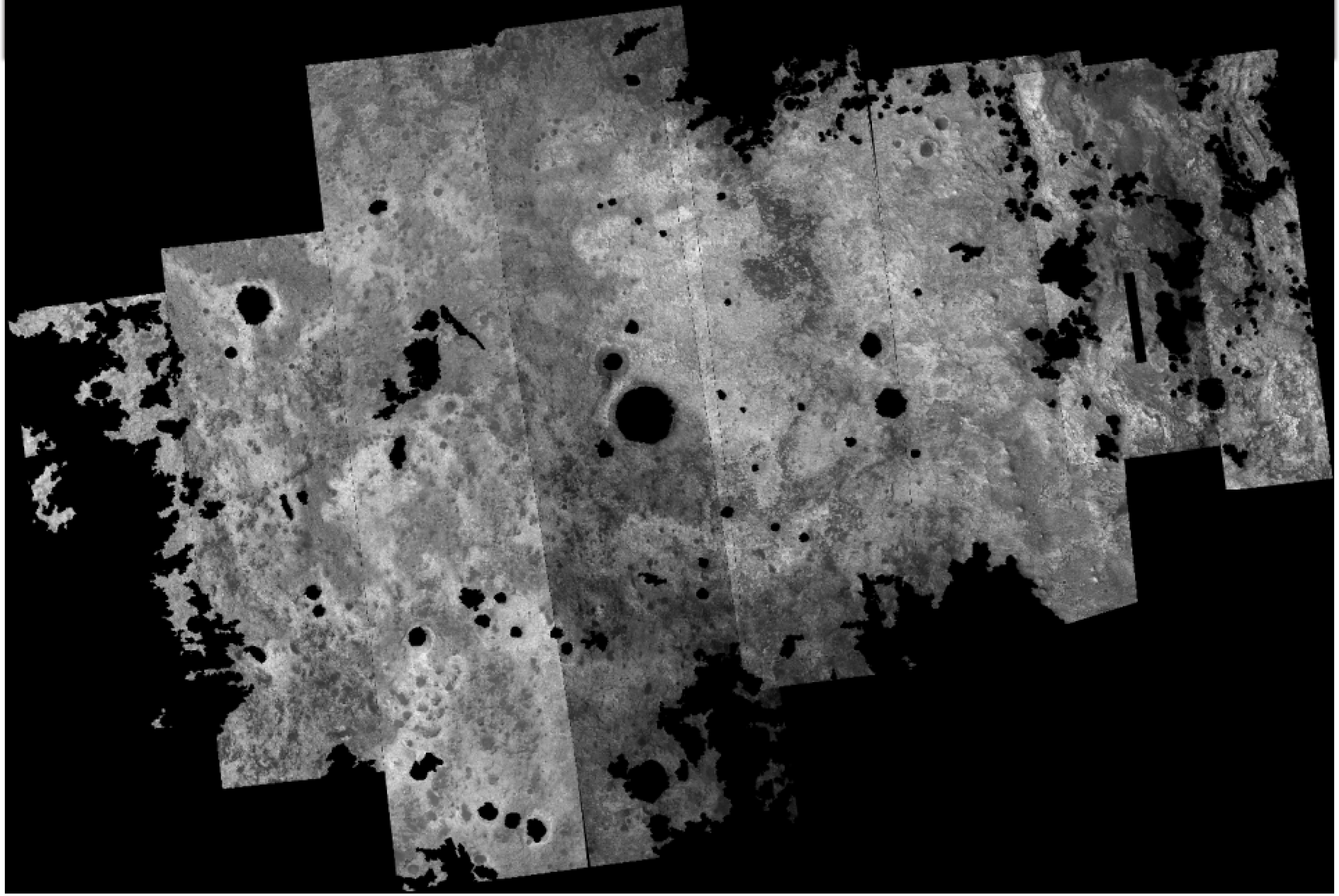
Geologic units identified on the basis of:

- Composition
- Thermal inertia
- Morphology

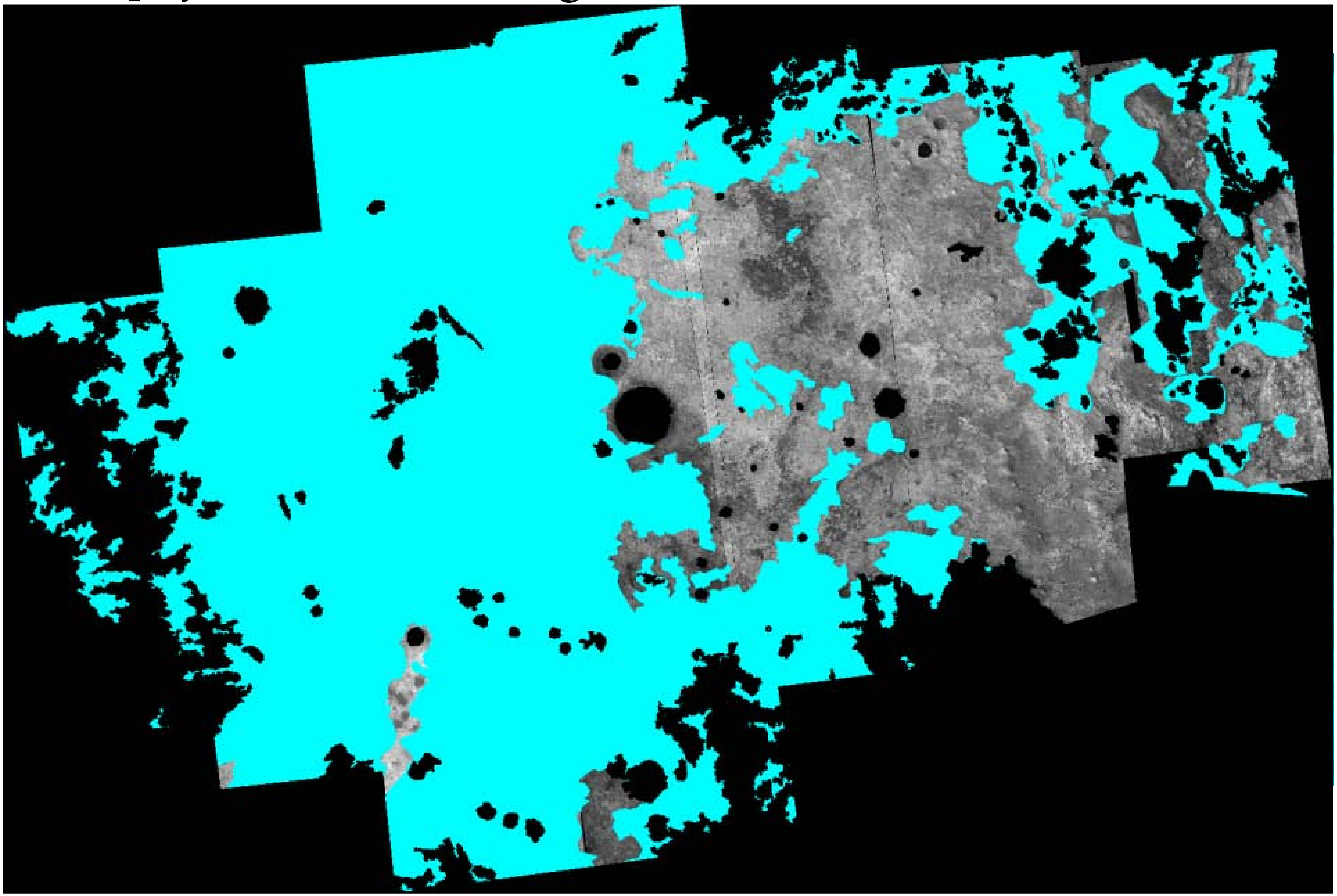

THEMIS/IR Nighttime mosaic



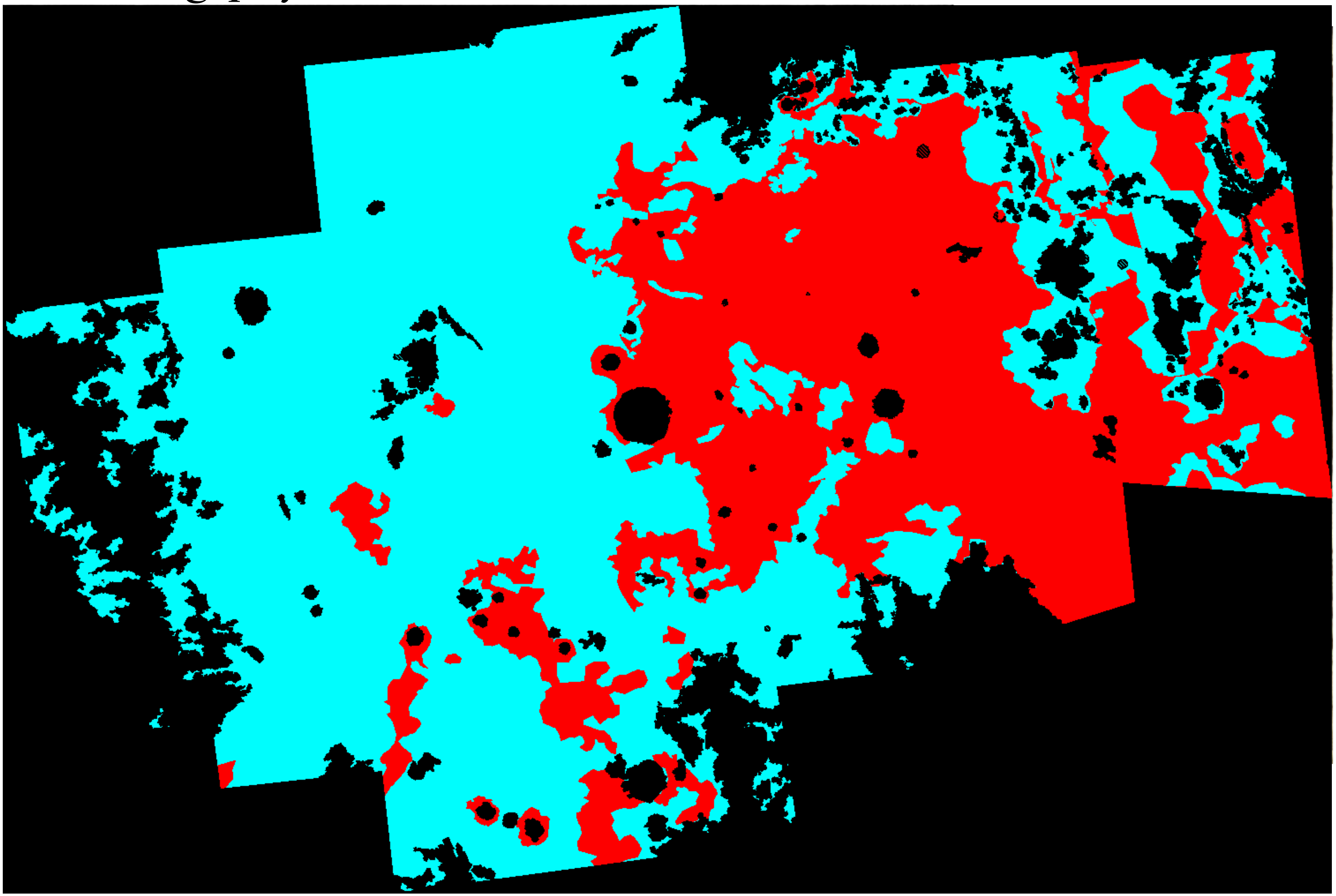
CAPPING UNIT



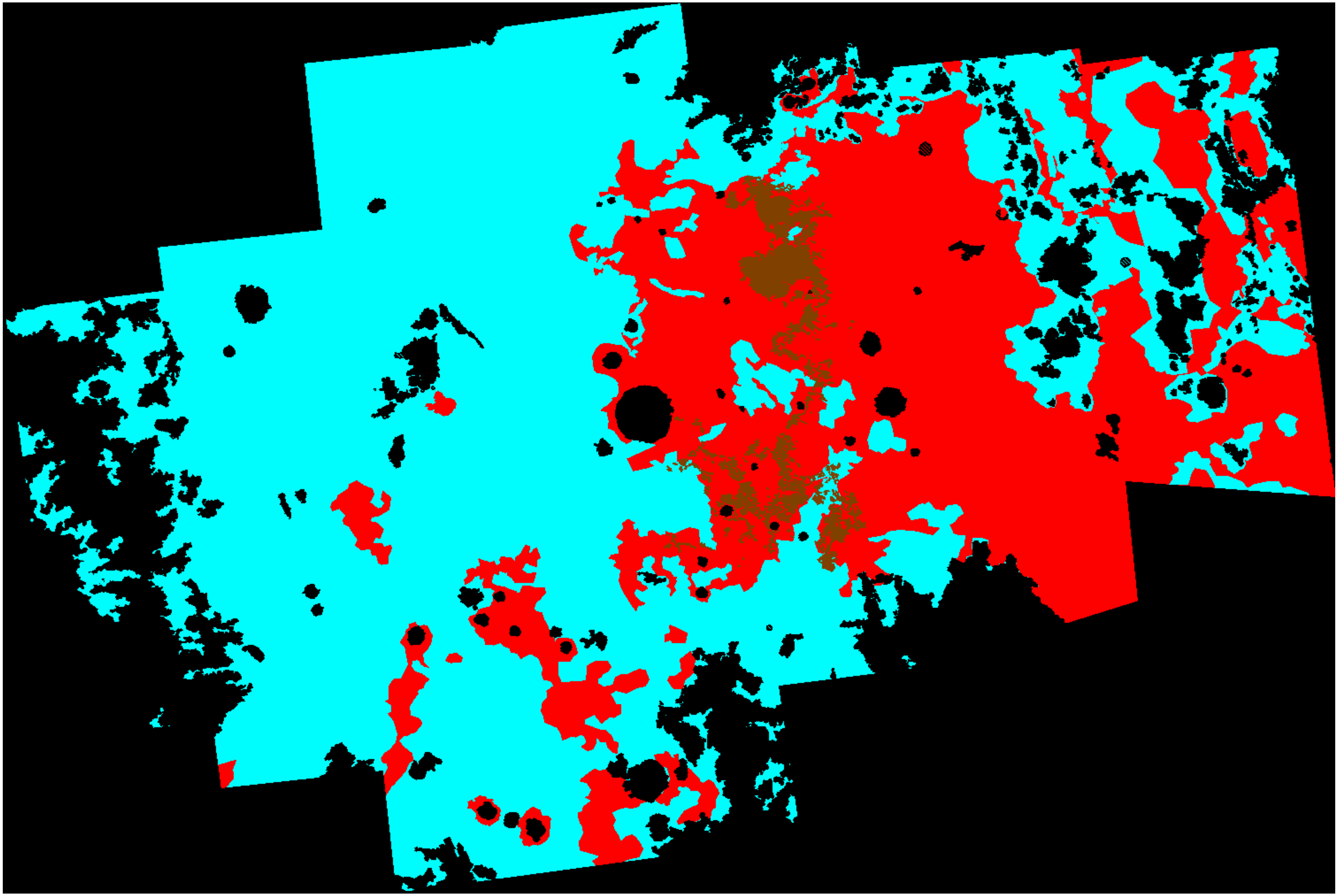
Al-phyllosilicate-bearing unit



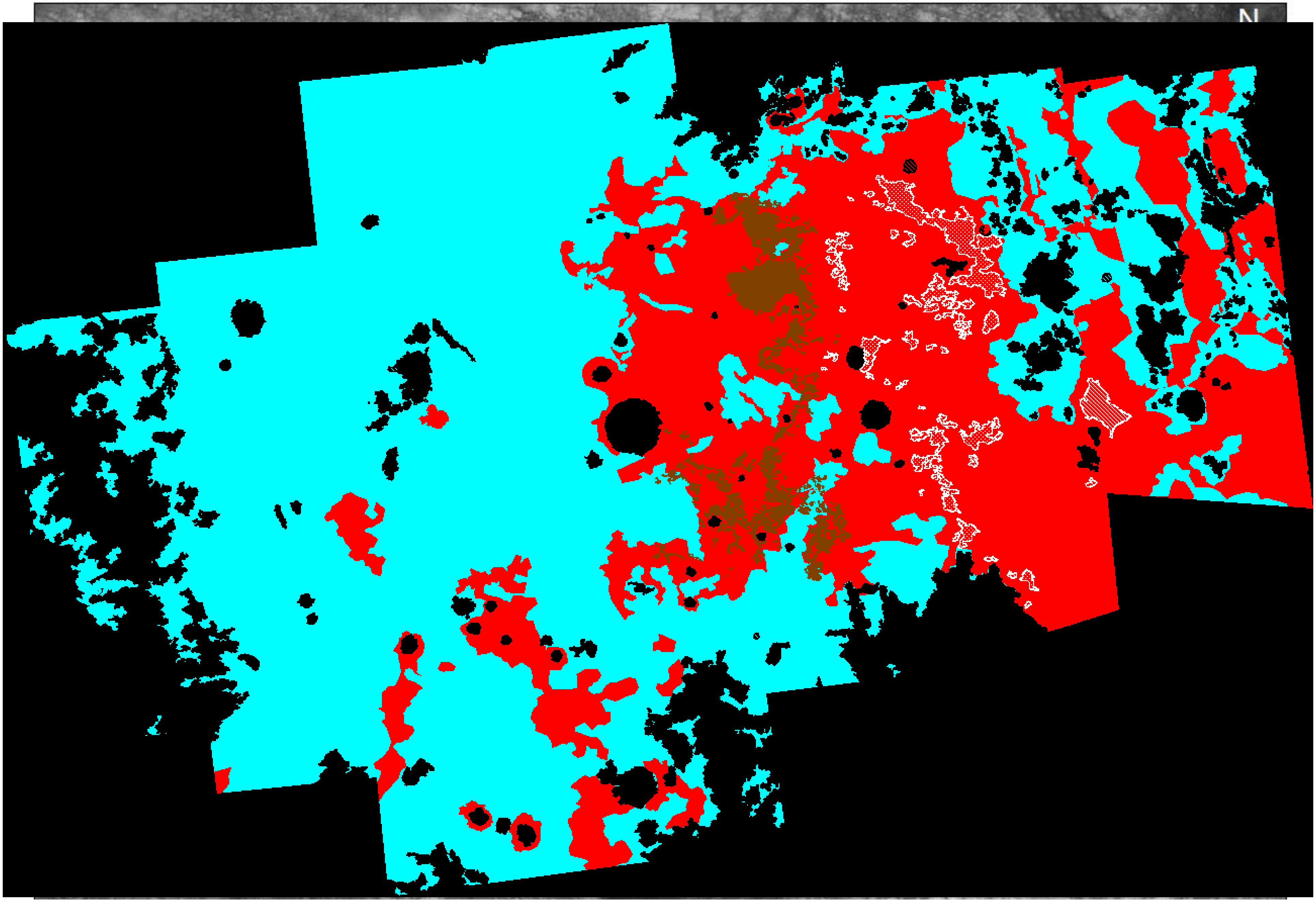
Fe/Mg-phyllosilicate BRIGHT RED unit



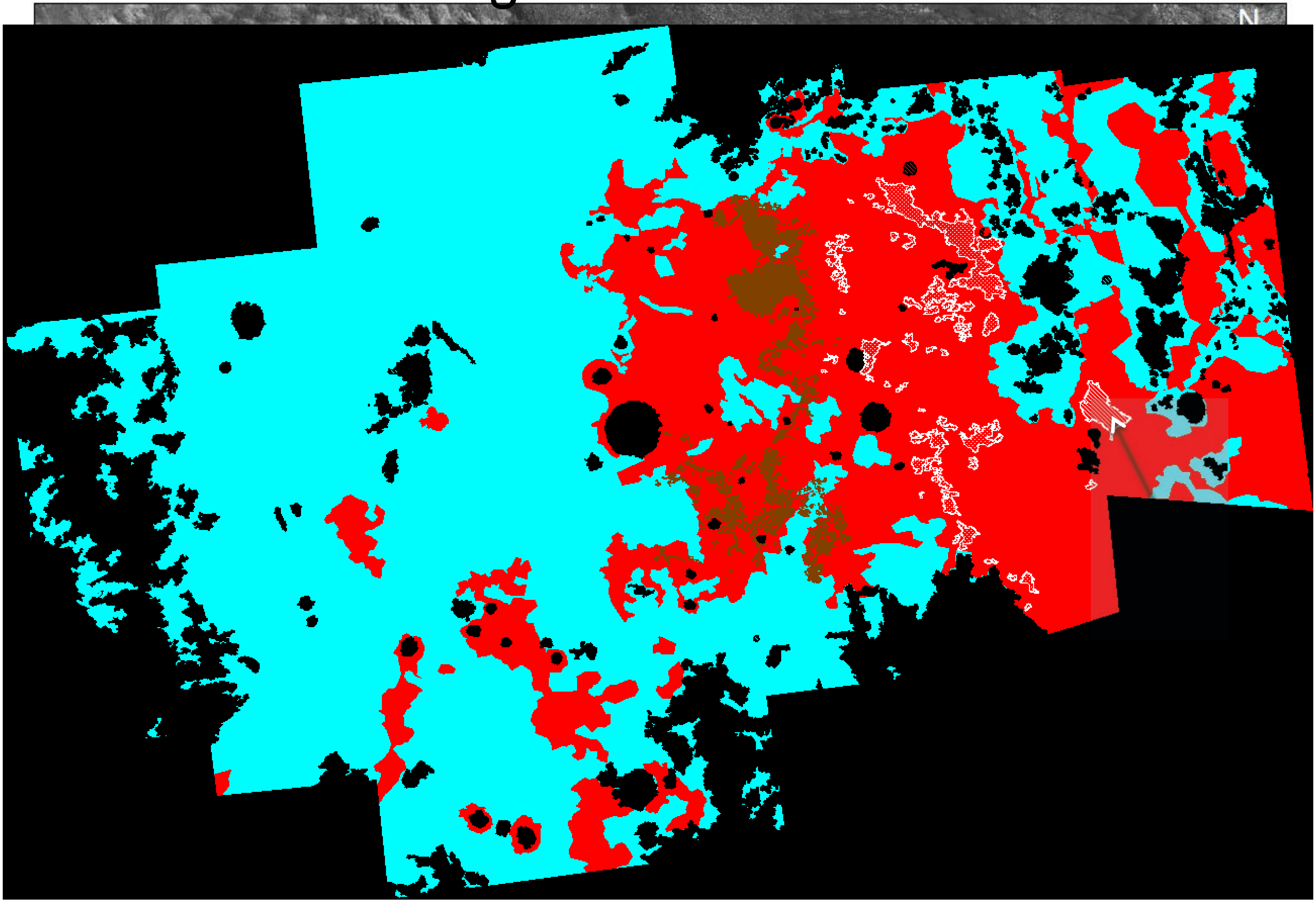
Dark units



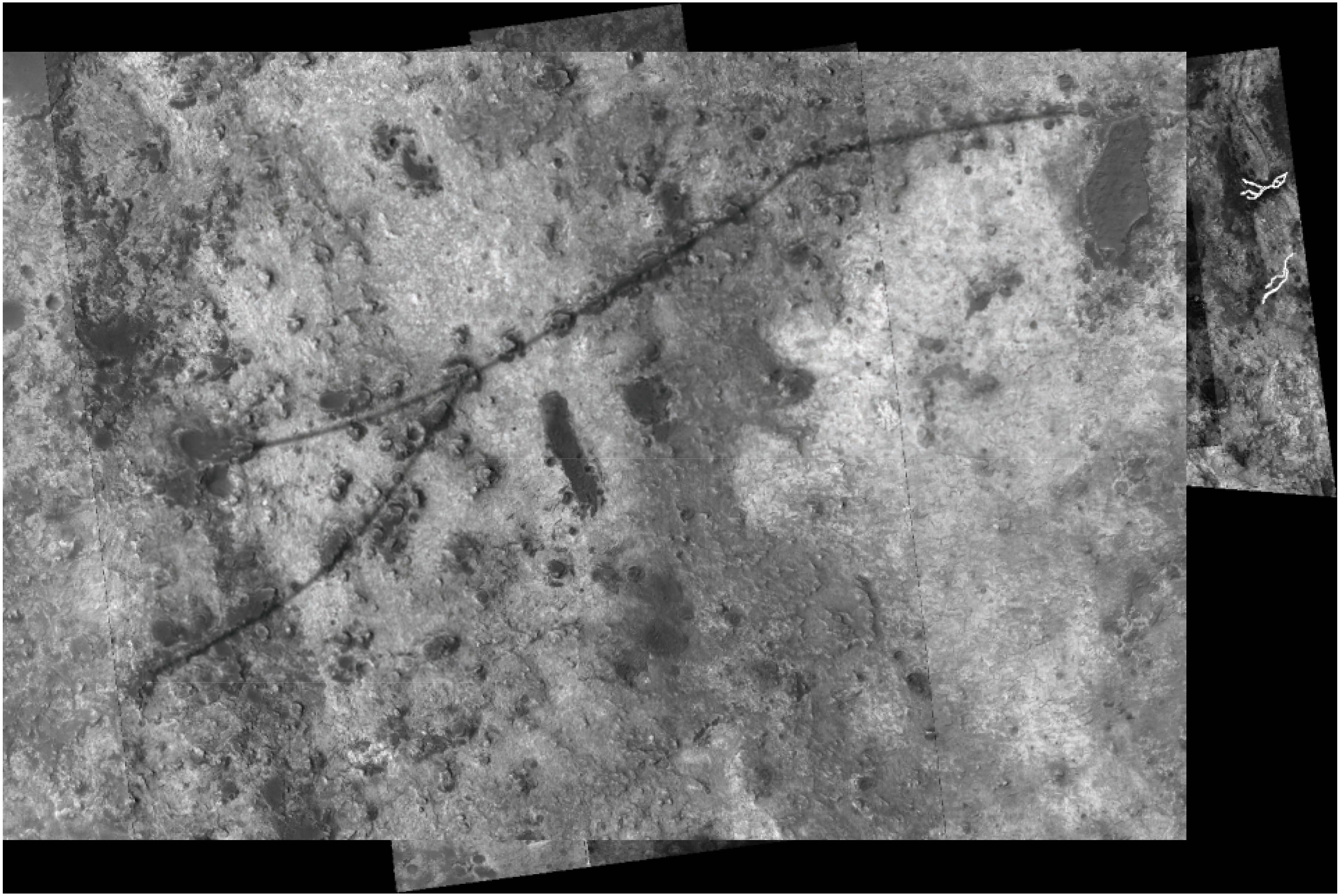
Pitted-and-etched BRIGHT RED UNIT

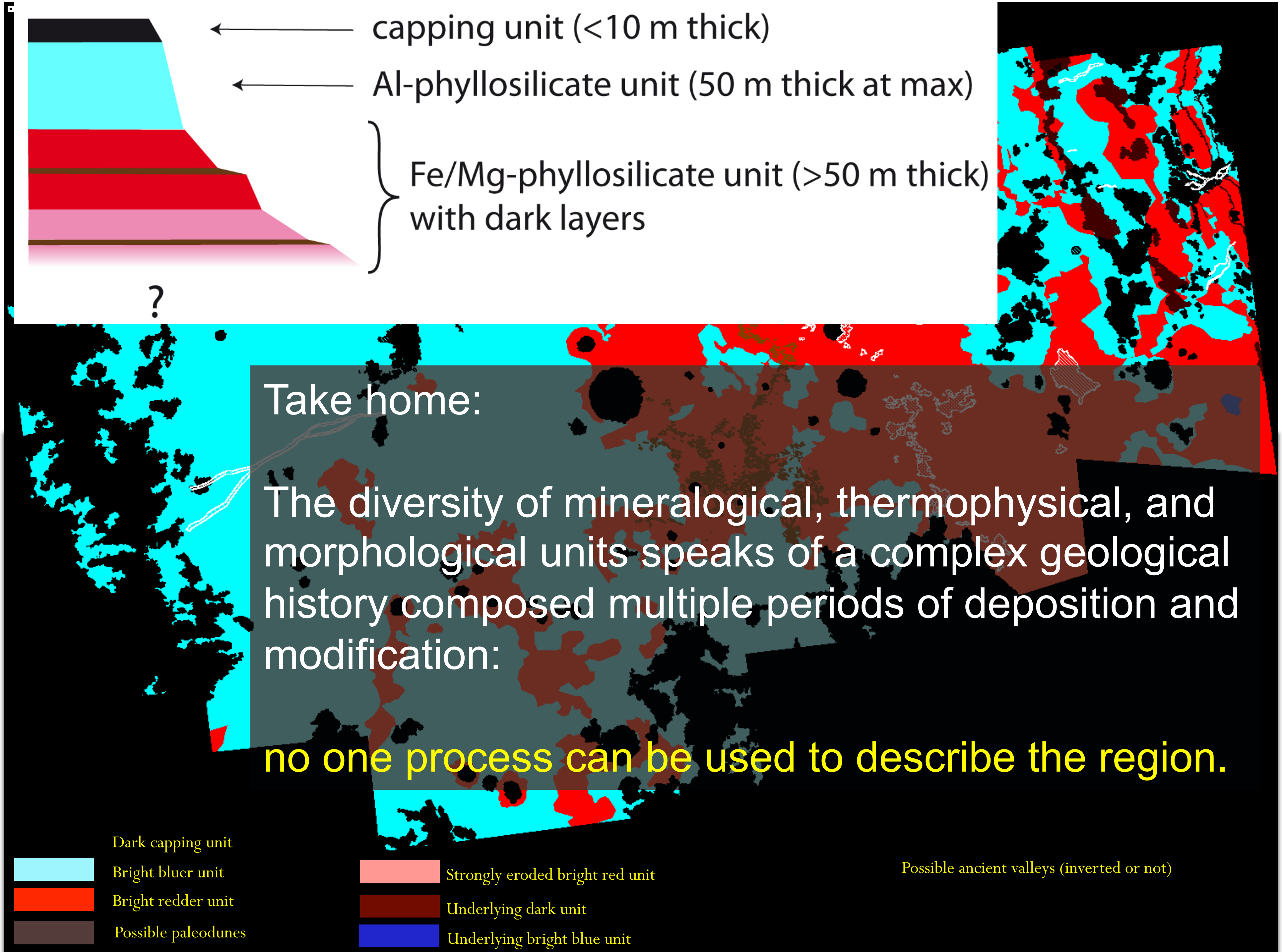


Inverted fracturing



POSSIBLE REMNANTS OF INVERTED VALLEYS?




capping unit (<10 m thick)
Al-phyllosilicate unit (50 m thick at max)
Fe/Mg-phyllosilicate unit (>50 m thick) with dark layers
?
Take home:
The diversity of mineralogical, thermophysical, and morphological units speaks of a complex geological history composed multiple periods of deposition and modification:
no one process can be used to describe the region.
Dark capping unit
Bright bluer unit
Bright redder unit
Possible paleodunes
Strongly eroded bright red unit
Underlying dark unit
Underlying bright blue unit
Possible ancient valleys (inverted or not)

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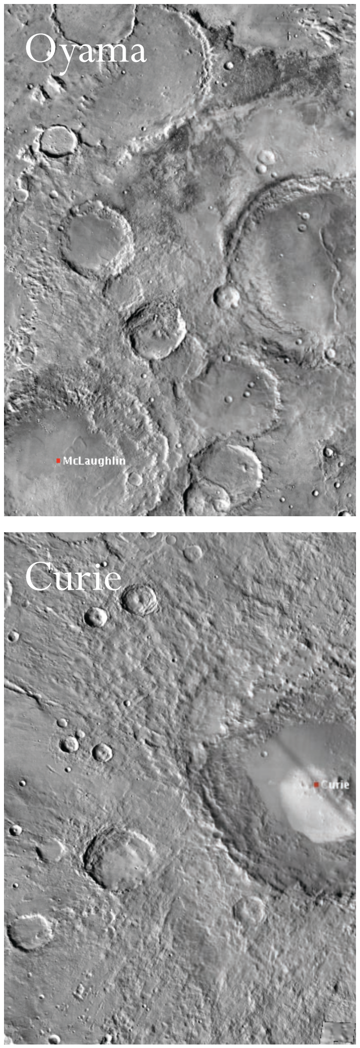
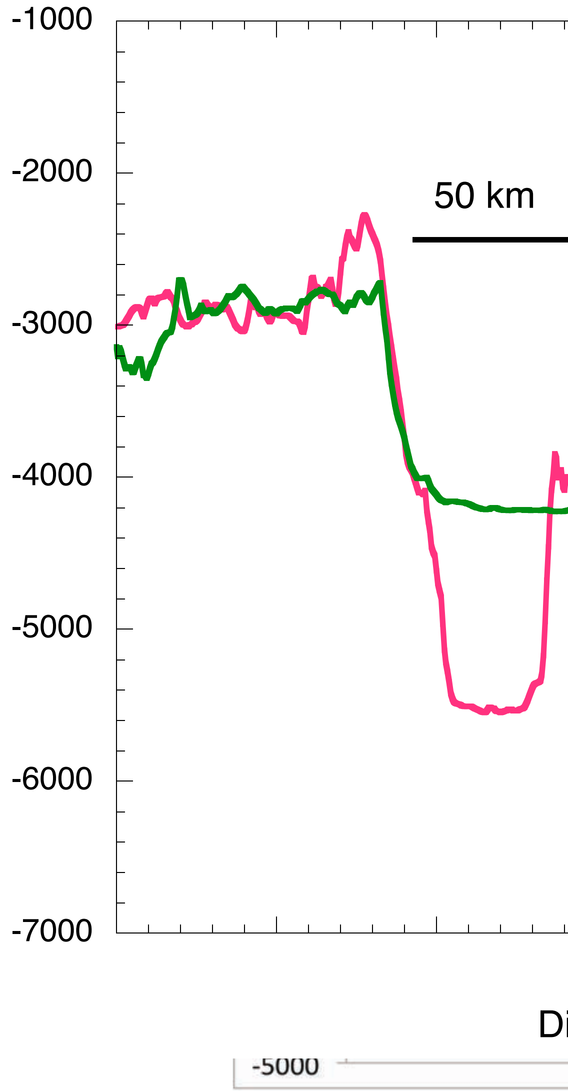
Where is Oyama's ejecta?

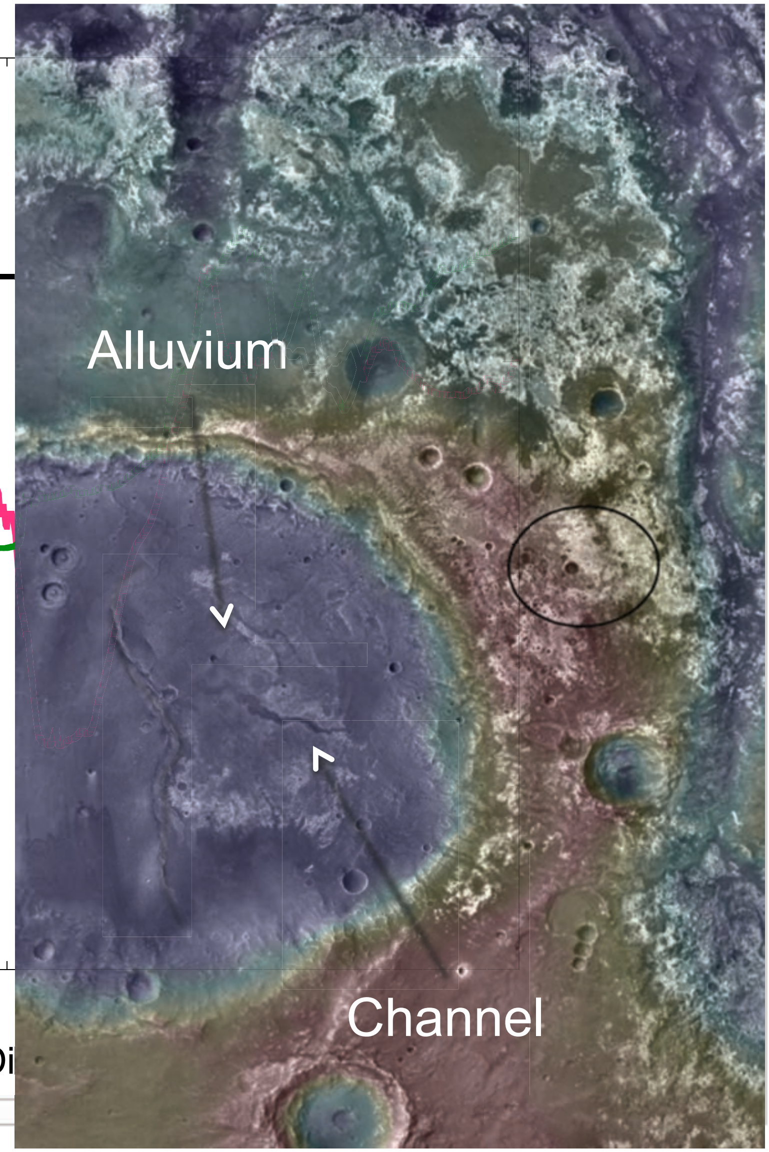
Michalski:

- Using equations from Cohen et al. [2006] and Pike [1974], we can estimate the amount of ejecta that should have been thrown out from a given crater
  - th = 0.33 x R x (r/R)^-3
  - R = transient radius; r = distance from crater; th = thickness of ejecta at some distance, r
  - Assuming a transient cavity radius (35-40 km), **we would expect an upper limit of 120-250 m of ejecta had been deposited on the ellipse center.**
- Rim height can be estimated using the following equation from Melosh (1989):
  - RH = 0.236 * D^0.399
  - **Oyama's rim should be about 1.3-1.5 km above the surrounding plains**
  - **It is approximately 0.5 km, implying significant erosion**
  - Most ancient Martian craters have been significantly degraded compared their counterparts on the Moon or Mercury (Malin and Dezurisin, 1977)
- **Take home: 1 km of rim material is gone or buried. Why do we expect to see 200 m-thick ejecta unit?**

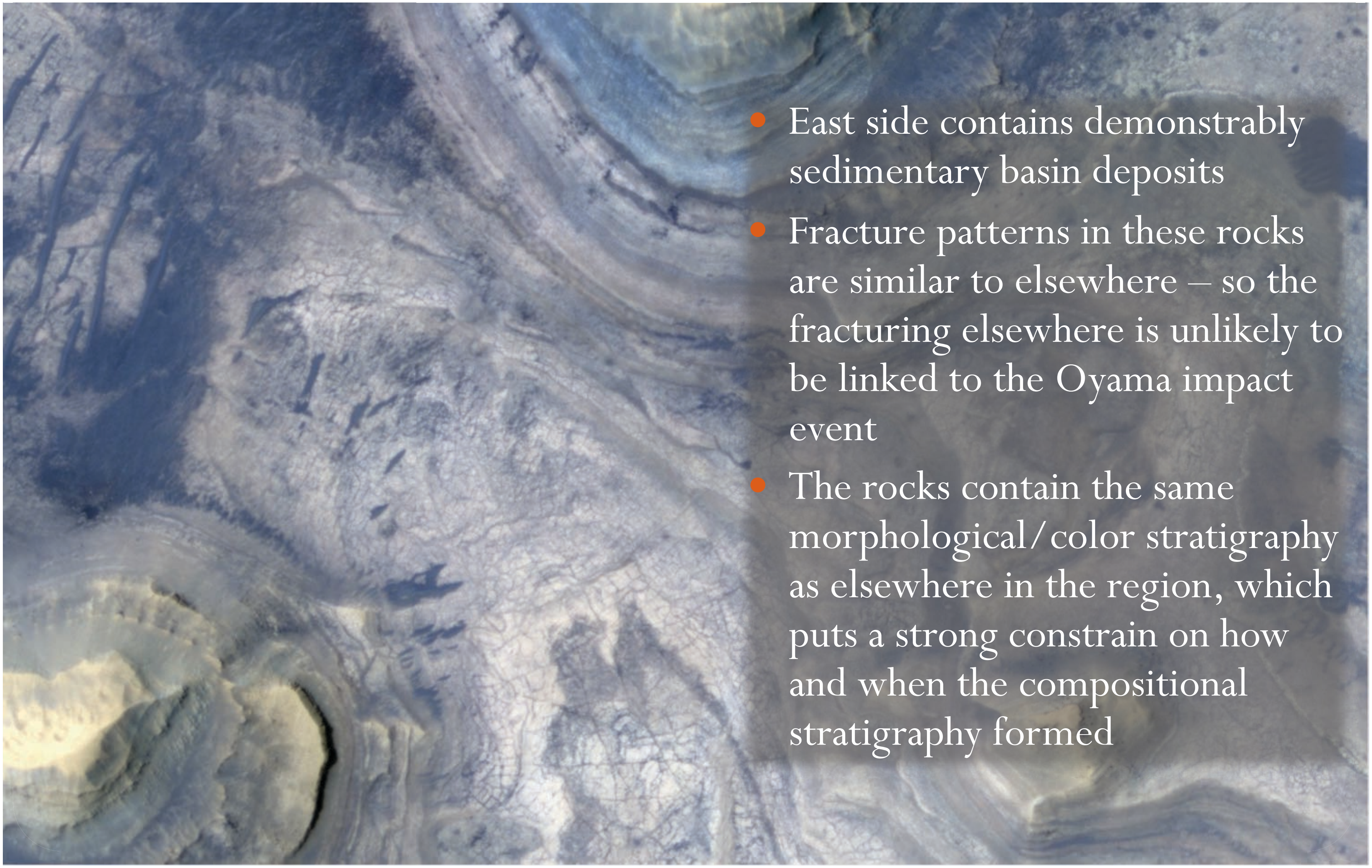
Degradation of Oyama Crater







Oyama crater floor deposits



- East side contains demonstrably sedimentary basin deposits
- Fracture patterns in these rocks are similar to elsewhere – so the fracturing elsewhere is unlikely to be linked to the Oyama impact event
- The rocks contain the same morphological/color stratigraphy as elsewhere in the region, which puts a strong constrain on how and when the compositional stratigraphy formed

Resurfacing history

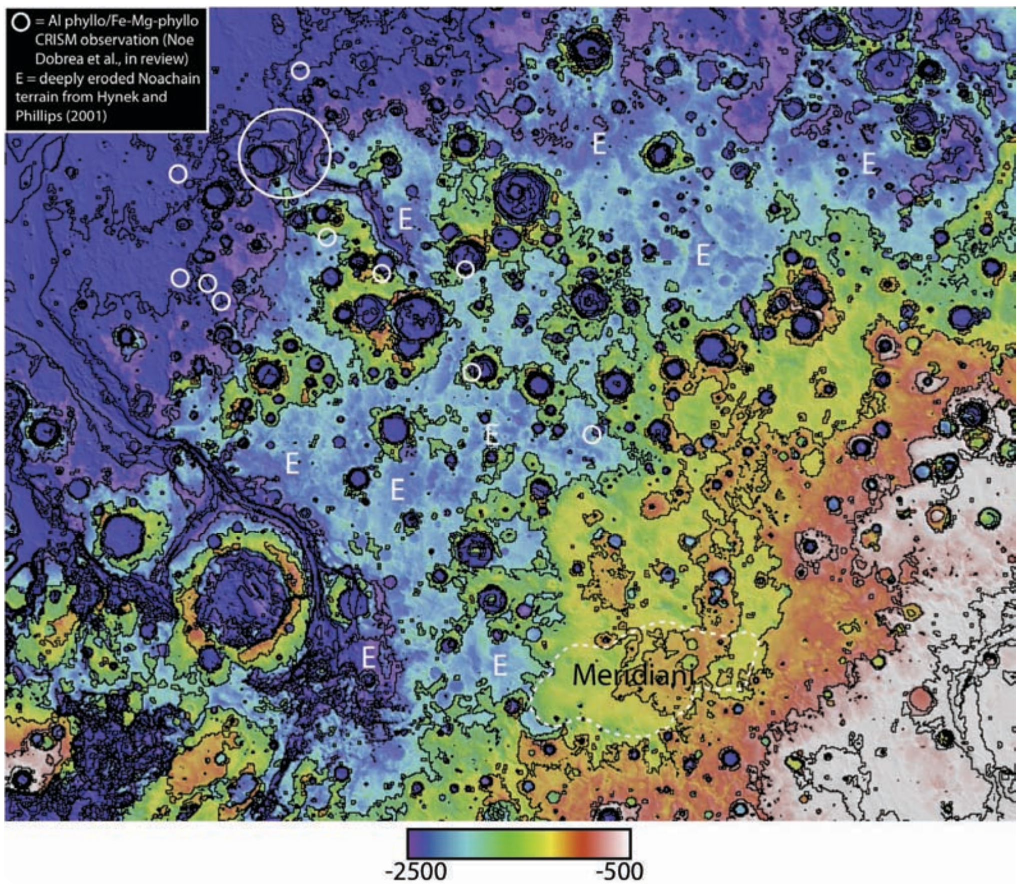
Evidence

- Inverted channels speak to fluvial history
- Possible draping relationships
- Remobilized clays in the channel floor and elsewhere and inside Oyama
- Absence of Oyama's ejecta

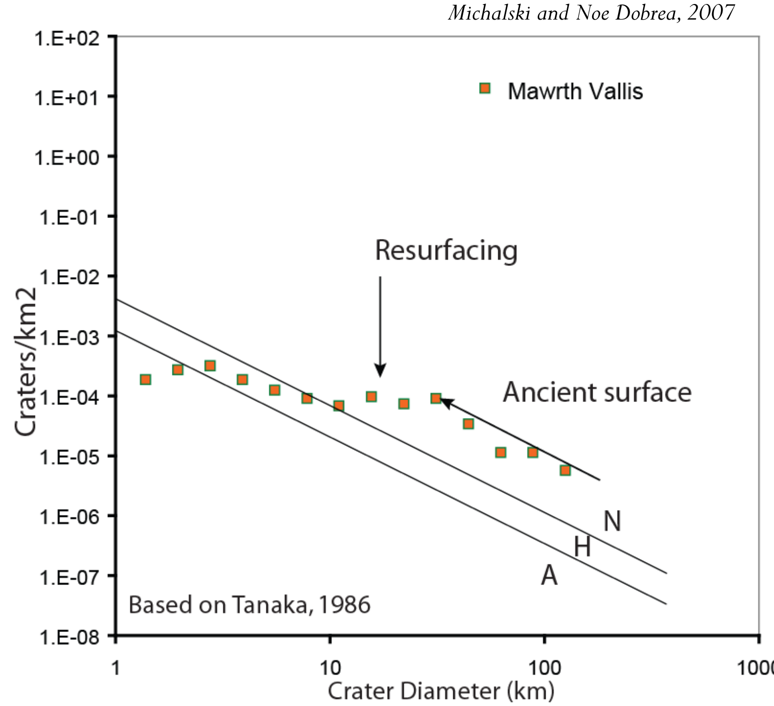
Use crater counting to constrain the age

RESURFACING

- The oldest cratering record is ~Mid-Noachian
- Craters <20 km were removed from the original record during a Late Noachian or Early Hesperian event
- Suggests km-scale erosion



Michalski and Noe Dobrea, 2007



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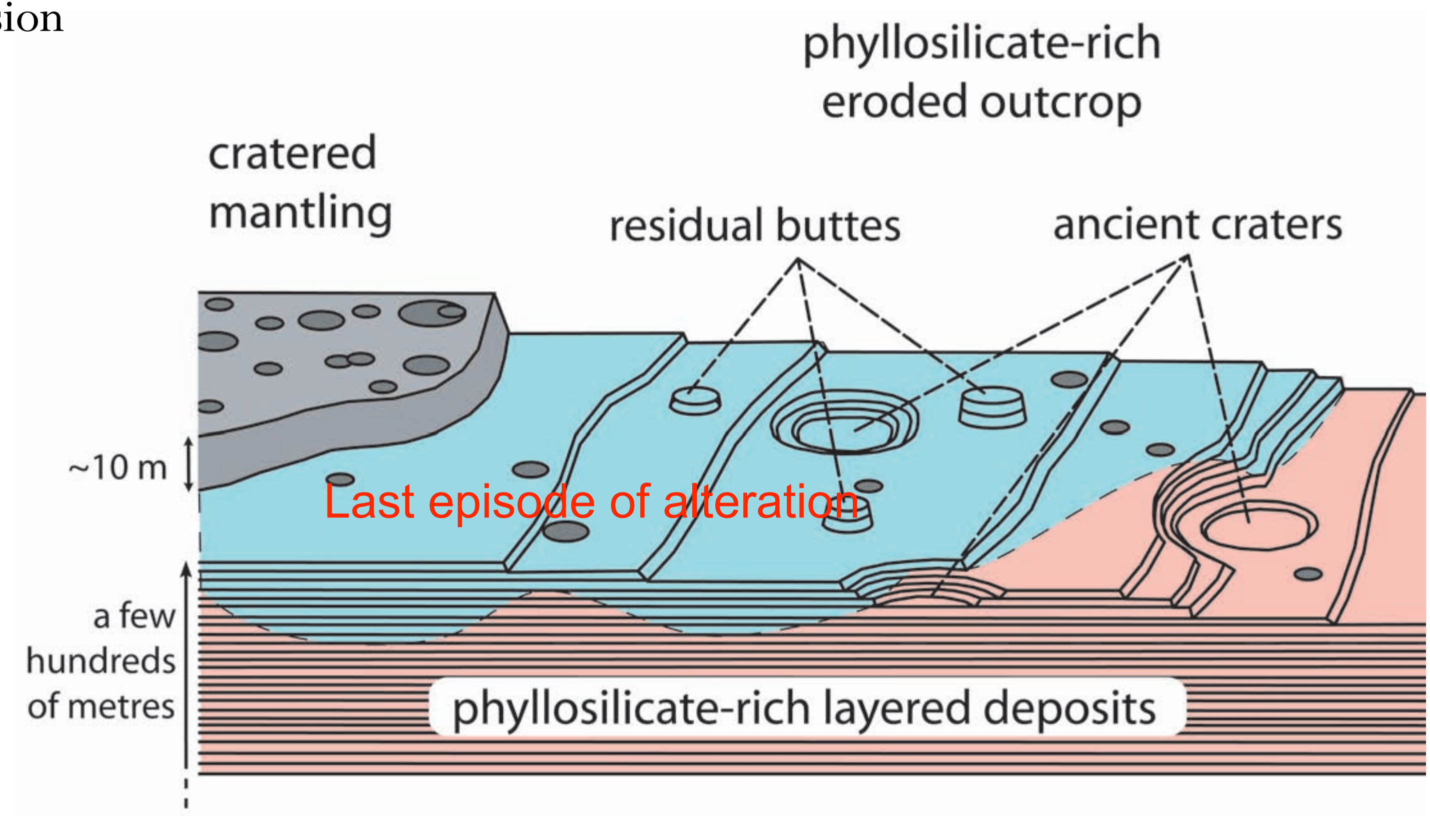
Summary: What we know

- The rocks are layered throughout the region
  - multiple lithologies or at least subtle differences between units
- Diverse geomorphic expressions
  - Complex geological history
- At least two phyllosilicate-bearing units:
  1) **Fe/Mg smectites** – noachian, excellent preservation potential,
  2) **Al-phyllosilicates, hydrated silica, and alteration products**
     - Possibly deposited as part of major resurfacing event?
     - Mineralogy suggestive of alteration and leaching – transition to acidic period?
     - Boundary between units sometimes contains an Fe^{2+}-bearing material
- Channels
  - cutting into Al-phyllosilicate unit
  - Suggests that fluvial systems existed after (and possibly during) deposition of Al-phyllo unit
  - Over 50 m of erosion since deposition of Al-unit
- Groundwater activity:
  - Pitted-and-etched terrain,
  - inverted fractures
- Composition and morphological units are repeated over scales of 1000 km
  - Representative of regional-scale lithologies and mineralogy

Summary: Alteration history

1- Deposition of a thick layered clay unit
2- Erosion of the surface (fluvial and aeolian)
3- Last episode of alteration
4- Deposition of the dark capping unit
5- Aeolian erosion



Formation models

- Any model must be able to explain:
  - The formation of 100s or 1000s of layers of rock over a thick stratigraphic section
  - Widespread occurrence of the layers, even if we cannot (yet?) correlate specific strata over great distances
  - Rocks were deposited and reworked over a duration of time (cratered volume)
  - Alteration mineralogy – formation or deposition of significant amounts of clay minerals
  - Compositional stratigraphy
  - Erosion and resurfacing, redistribution of sediments

Formation models

- We can rule out:
  - Lava flows
    - Nothing about the geomorphology, geometry, mineralogy, structure, or context is similar to lava flows altered under any reasonable circumstances
    - There could be a lava flow or several somewhere in the section if the section really represents hundreds of My, but there is no evidence for it at this point
  - Amazonian surface weathering
    - Nothing suggest a similarity to recent weathering patters, weathering rinds, rock coatings, etc (not to say these things don't exist because they probably do, but this does not explain the important aspects of geological observations)
- Remaining ideas:
  - Altered sedimentary materials (marine, lacustrine, fluviolacustrine);
  - impactites, pyroclastics subsequently altered
- Must consider:
  - The origin of the clastic materials (layers) and the origin of the alteration separate (i.e. consider diagenetic alteration of an otherwise unaltered column of rocks)

Formation models

Model	Pros	Cons
Impact ejecta	•Lots of impacts during noachian	•Tends to make unconsolidated, poorly sorted rock layers, •does not explain composition or lithological variability
Airfall deposits (impact-generated fines, pyroclastic, etc)	•Expected geological processes	•Need 100s-1000s of events, • does not explain composition or lithological variability
Fluvio/lacustrine	•A large system is conceivable, could explain extensive units, • Can probably explain the mineralogy, •Many subtly different layers explained by dynamic system where each layer is a tabular volume	•Need enclosed topography of lacustrine system •Need thicker atmosphere to support for extended period
Marine	•Same as fluvio/lacustrine •Provides an enclosed basin	Need to figure out how to get rid of all that water!

Geological Evolution Models

1 (sedimentary)

Deposition of fluvio/lacustrine sediments

2 (volcanic/diagen)

Deposition of sequence of unaltered volcanic material (mafic → felsic)

Aqueous alteration
→ Al-OH from felsic
→ Fe/Mg smectites from mafic

3 (volc/dia/pedogen)

Deposition of unaltered volcanic material (mafic)

Alteration to Fe/Mg smectites

Leaching of upper layers
→ Al/Si-OH

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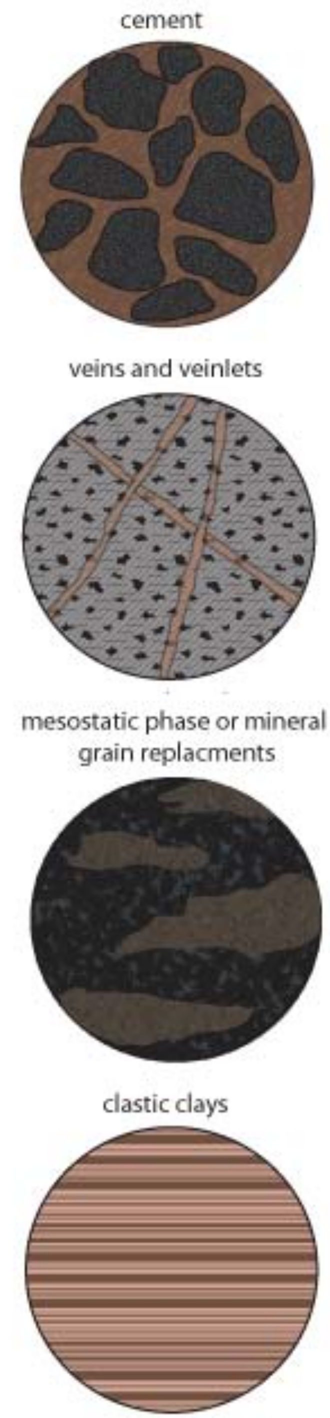
What we don't know

- Origin of phyllosilicate-bearing layers
  - Volcanic? Impact ejecta? Lacustrine? Fluvial? Aeolian?
- Origin of Fe- and Al-phyllosilicates
  - Precipitation? Transport? Diagenesis?
- Nature of the contact between Al- and Fe-phyllosilicates?
  - Depositional? Diagenetic? Top-down alteration?
- Extent and pH of water during period of dissection of Al-bearing unit
  - Was water stable at the surface? What was its pH
- Nature of cap unit?
  - Volcanic? Impact gardening? Aeolian?

MSL can address these

- Mastcam
  - relationship between layers and phyllosilicates – do color boundaries cross layer boundaries in bedrock (diagenesis, pedogenesis)?
  - assess bedding (fluvial, aeolian, lacustrine)
- MI
  - Grain sizes and shapes, particle sorting, texture, cementation
- CheMin, APXS
  - elemental gradients across layers (diagenesis, evaporites, pedogenesis),
  - mineralogical assemblages of sediments (hydrothermal/ metamorphism) and fracture cements
  - searches for carbonates to assess past thickness of atmosphere and stability of liquid water (fluvial, lacustrine vs groundwater alteration)



Conclusions

We are seeing some of the most ancient units on Mars

Representative of (at least) – regional-scale processes

Abundant "true" nontronite – neutral conditions, no metamorphism

Transition to more acidic conditions preserved in stratigraphic record

Clear and complex history of aqueous activity

overland flow (channels),

underground water (pitted-and-etched terrain),

(possibly) top-down alteration (acid-treated clays, kaolinite)

Lithology and layering suggest complex depositional history

Finally, important transition to the Hesperian capping unit.